NEMS FOR SPACE AND TERRESTRIAL APPLICATIONS

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Nanoscale electromechanical systems (NEMS) techniques were used to manufacture a membrane used to supply singly charged un-fractured ions for mass spectrometry. The innovative nanostructure, developed at the Jet Propulsion Laboratory (JPL), is a major advance over micromachined "volcano" field ionization devices and filaments or other energy-intensive devices, achieving nearly 100% ionization of gases and vapors without appreciable fracture [1,2].

The 'soft' ionization membrane (SIM) is a composite structure consisting of electrodes, insulators, and support structure. Figure 1 illustrates the concept, which is realized by micro-machining very small holes through a thin (sub-micron) membrane that has metal electrodes on each side of it. Figure 2 shows the resolution of the manufacturing methods, where all dimensions may be controlled to very tight specifications. Ions are created in the submicron structures in the membrane by extreme electric fields (millions of volts per meter per volt of applied potential). Because the flight-path of gas molecules between collisions is greater than the electrode separation (beneath Paschen curve) few secondary collisions occur that can split larger molecules and only singly charged ions are produced.

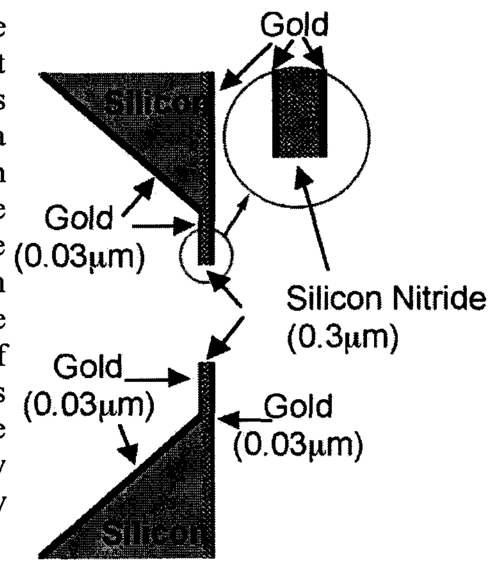

Figure 1. Single Pore Element of the Soft Ionizing Membrane

Ionization that does not fragment or multiply-ionize the sampled species is a boon to many ion discrimination instruments. Further, the efficiency of the ion stream is expected to provide the detection of vapor-phase compounds at the 10 parts-per-trillion level, performance that exceeds many detection capabilities by up to five orders of magnitude.

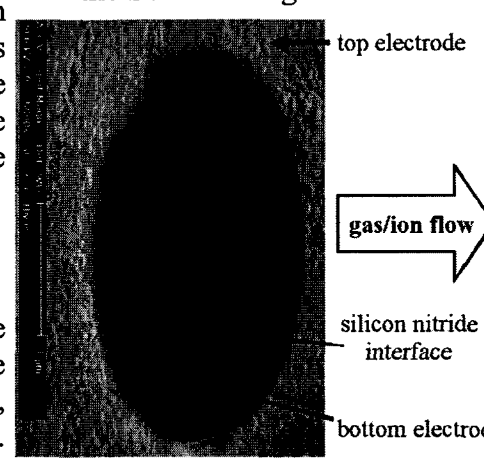

Figure 2. Photomicrograph of Pore

SIM Membrane for Mars Exploration

To investigate the chemically active and diverse atmosphere of Mars, a revolutionary gas analyzer using the SIM was developed that has very low power requirements, has a mass less than one kilogram, and is highly robust. The SIM is married to a rotating field mass spectrometer configured for lower molecular weight gases. The

Rotating Field Gas Analyzer (RFGA) focuses ions by means of a combined applied DC and a rotating electric field that collimate and separate the ion beam. The principles are shown in Figure 3, where the ions entering a small chamber are accelerated towards a detector by the DC field while being forced into a helical path by the rotating field. The resonant helical route taken to the detector provides for separation of ions in a remarkably short chamber [3,4]. The RFGA was developed at the Jet Propulsion Laboratory [5], and is in use for remote measurements of volatiles in deep ocean environments [6].

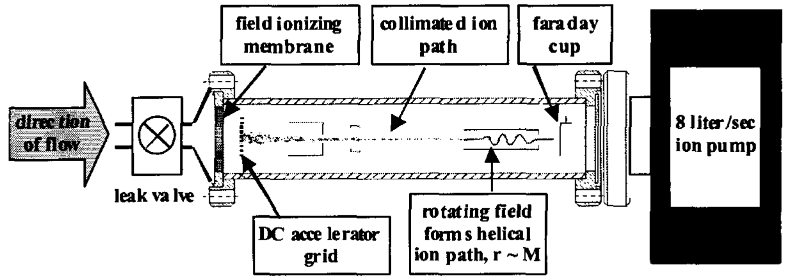

Figure 3. SIM-RFGA Elements

The SIM-RFGA is uniquely suited to Mars exploration [7,8]. It can be operated at low Martian polar temperatures, can be self-calibrated, is small and lightweight, requires less than 10 watts, and can be made tolerant of high landing forces and spacecraft-related pyroshock. Unlike other mass spectrometric methods, adjustments to unforeseen dimensional stresses can be made *in situ* by corresponding adjustments in the electronic environment alone. When adapted specifically for use in the Mars atmosphere, the SIM-RFGA will have high mass sensitivity (up to ~1000 $m/\Delta m$) with conventional ion detectors, making full determination of the important atmospheric components possible. Both the RFGA and elements can be operated at pressures up to about 30 hPa (30 mbar, 25 torr) without the need for high vacuum, allowing for the *possibility* of pumpless and self-sampling operation at Mars atmospheric temperatures and pressures (~6 to ~15 hPa). With accompanying pressure and temperature measurements, the SIM-RFGA is self-calibrating and, with suitable electronics, self-adjusting to extreme environmental changes [9].

SIM Technology for Human Exploration of Space

There are currently no sensors that are capable of monitoring both a spacecraft's air and water environment for trace contaminants to the standards required by NASA. The Atomic and Molecular Collisions (AMC) Team at JPL have designed the OmniSPEC around a miniature MS and microGC developed previously under the NASA Code U program. The GCMS core of the OmniSPEC has already demonstrated its ability to separate most compounds at Spacecraft Maximum Allowable Concentrations (SMACs) sensitivities using direct electron-impact ionization techniques that have about 0.001% efficiency [10,11,12]. A NASA NRA [13] has been submitted that will integrate the SIM with the OmniSPEC to give parts-per-trillion sensitivity that significantly exceeds (by several orders of magnitude) the SMAC levels requirements. The result of such overcapacity is that speed, reliability and safety are fundamentally enhanced. Trace health contaminant systems have obvious dual uses. The OmniSPEC will also be capable of terrestrial applications in the fields of counter-terrorism and public safety.

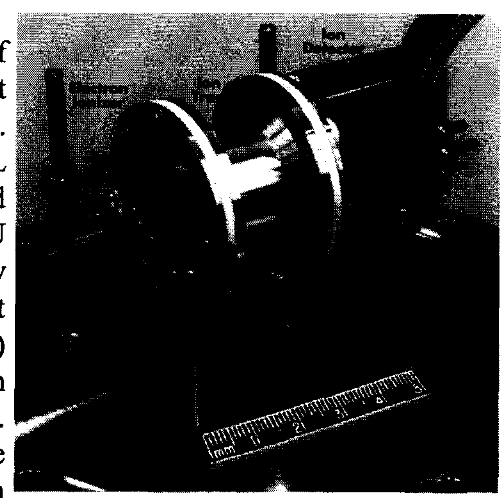

Figure 4. Compact Paul ion trap used in the OmniSPEC.

SIM Technology for Planetary Exploration

The JPL Atomic and Molecular Collisions (AMC) Team has also designed, built and tested a flight multifrequency quadrupole mass spectrometer array (QMSA) [14,15]. A proposal has been made to highly miniaturize the QMSA using the SIM combined with miniature electronics and a miniature sensor [16]. A stand-alone system of wide mass range, high sensitivity, excellent resolving power, and large dynamic range and of extremely low mass-power-volume (MVP). The high ionization efficiency of SIM is expected to increase the sensitivity of the MS by a factor of more than 100 over that achieved via conventional electron-impact ionization.

Given the trend of more frequent, lower-cost missions, and the desire to complete planetary exploration by flying to the Outer Planets, the self-contained, SIM-QMSA systems will enable new scientific instruments for both manned and robotic space aeronomy, and for surface composition at planets and satellites. For example, one can place several MSs on separate planetary rovers; or into separate orbits in the Io torus to study the time development of the neutral and ion densities from volcanic activity. Robotic missions to Uranus, Neptune, Pluto and Triton are enabled, given the low MVP of the SIM-QMSA. Long-duration human flights to Mars can use the SIM-QMSA system to monitor the cabin atmosphere at the trace-gas (SMAC) levels.

SIM Technology for Exobiological Exploration

Gas chromatography/mass spectrometry (GC/MS) is perhaps the most prominent of techniques presently available for the analysis of organic compounds from a landed spacecraft. In fact a GC/MS was successfully utilized on the Viking Mars lander, and will be part of the European Space Agency's Beagle II Mars probe in 2003. The Huygens probe also carries a GC/MS, launched aboard Cassini spacecraft, for the detection of molecules in the atmosphere of Titan. However, conventional GC/MS detectors have inadequate sensitivity for detecting large organic molecules such as amino acids, or microorganisms such as bacteria, at the parts-per-billion level (a requirement for exobiological analysis on Mars [17]).

"Hard-ionization" fragmentation of mixtures of organic components complicates the complexity of breakup patterns severely constraining the quantitative analysis of components; and high vacuum requirements greatly increase the size, weight, power and mechanical complexity of instrument. An analyzer utilizing a SIM ion source simplifies the mass spectrum, making possible many measurements with additional precision and enabling others where fragmentation of complex species masks the desired signal. Detectors that can use both SIM and fragmenting ion sources offer even greater opportunities for identification of complex species.

For the difficult problem of separation and identification of isomers, the NEMS-produced SIM can used in combination with ion mobility devices. The JPL Instrument Development and Spectroscopy Team has demonstrated a new high-resolution Ion Mobility Spectrometry (IMS) for detecting various types of amino acids, large organic molecules [18,19], bacteria (E. coli) [20] and some protein isomers [21]). A NASA NRA proposal [22] has been submitted that will integrate the SIM with the IMS to create a new detection technique to be known as "SIMIMS". The SIMIMS instrument will possess high sensitivity, will not fracture medium, will offer an improved molecular range, will discriminate isomers, and will not require high vacuum for operation.

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